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CHARGE BREEDING METHOD RESULTS WITH THE PHOENIX BOOSTER ECR ION SOURCE

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Abstract

The charge breeding method using an Electron Cyclotron Resonance Ion Source (ECRIS) have already shown interesting results when injecting a 1+ ion beam into the dedicated PHOENIX Booster ion source developed at ISN-Grenoble with a 10 GHz RF frequency transmitter. New results have been obtained with a 14 GHz RF frequency and new elements have been studied to get reliable efficiencies and charge breeding times suitable for an easy and daily production of multi-charged Radioactive Ion Beams. The cw regime is suitable for cyclotron acceleration when the Electron Cyclotron Resonance Ion Trap one, fulfils the requirements of pulsed accelerators as linacs and synchrotrons. The afterglow measurements performed give a better understanding of the physical processes involved in the ECR-plasma production of highly charged ions and could lead to improvements of ECRIS efficiencies and therefore to accelerator ones.

1 INTRODUCTION

The purpose of this publication is to focus on two major points concerning the ability of the ECRIS PHOENIX Booster and its injection system to produce either radioactive ion beams (RIB) or metallic ion beams suitable for an efficient acceleration. The highest primary beam capture and fast charge breeding time τ_{cbt} are expected. The global efficiency $\eta_G(n,I_n,I_1)$ is the sum of the specific charge efficiency yields η_n, where n and I_n are respectively the charge and the intensity of the boosted charges obtained from the 1+ ion intensity injected I_1. η_G includes three processes: capture, ionization and extraction from the ECR plasma.

$$\eta_G = \sum_n \eta_n = \sum_n \frac{I_n}{n * I_1}$$

2 EXPERIMENTAL SETUP AND PROCEDURE

2.1 Experimental setup

The ISN charge breeding test bench has been extensively described in many publications [1-4], some improvements have been carried out concerning the vacuum (increase of the PHOENIX injection side pumping speed), and the alignment of the 1+ injection line.

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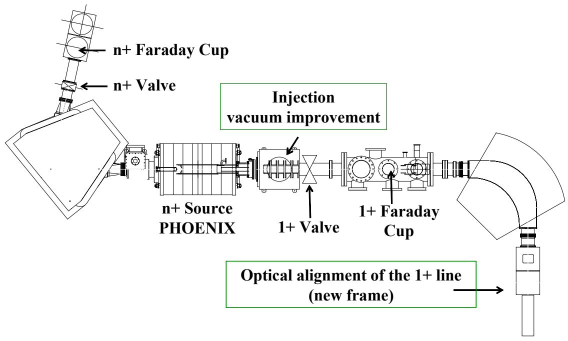

Figure 1: ISN 1+ → n+ experimental setup.

2.2 Experimental procedure

To prove the reliability of the 1+ → n+ method, 10 different ions have been injected in 15 days. The purpose of the experiment was to study the n+ production for A/n ≈ 7 ions (A: ion mass in amu) necessary to meet TRIUMF RFQ requirement. The system was tuned to get η_n = 3% and the charge breeding time τ_{cbt} (time to reach 90% of maximum intensity) was then measured. Concerning the production of stable metallic ion beams, the feasibility of reliable high currents has been studied.

3 CHARGE BREEDING OF RADIOACTIVE IONS

3.1 New elements injected in PHOENIX Booster 14 GHz

The new 1+ ions injected in PHOENIX Booster 14 GHz are ^{20}Ne, ^{23}Na, ^{39}K, ^{64}Zn, ^{69}Ga, ^{85}Rb, ^{88}Sr, ^{90}Y, ^{115}In, and $^{208}Pb^{2+}$ (due to the magnetic rigidity limitation of the 1+ spectrometer). Already studied elements ^{109}Ag and ^{120}Sn [3], have been injected too. The efficiency yields obtained in routine operation are summarized Table 1.

Table 1: Efficiency yields obtained for routine operation (one ion per day)

Element	1+ Intensity (nA)	n+ Charge	Yield (%)
^{20}Ne	1000	4	7.5
^{23}Na	660	6	1.3
^{39}K	280	6	6.5
^{64}Zn	42	10	2.8
^{69}Ga	460	11	2
^{85}Rb	90	13	5
^{88}Sr	470	14	3.7
^{90}Y	178	14	3.3
^{109}Ag	175	17	3
^{115}In	130	18	3.3
^{120}Sn	167	19	4.1
^{208}Pb	700 (2+)	25	6.8

The dispersion of the results is due to the experimental procedure described above in 2.2. Rare gases ions (i.e. ^{20}Ne) when approaching a wall are neutralized, and then can go back to the plasma where they are still available for subsequent ionization. In this situation the 1+ → n+ efficiency is always high. However for alkali or metallic ions this process does not occur since these ions can stick to the walls, so the radial diffusion is a loss term for the global efficiency.

3.2 Charge state distributions

Many experiments have been performed to obtain the highest efficiency on a specific charge. When the parameters are optimized to get the highest capture (η_G maximized), the ions can be considered as 'classical' ions in the ECR plasma, and thus the charge state distribution (CSD) doesn't differ from a classical ECRIS [5]. We can now consider that, for metallic ions with A ≥ 40 amu we get $\eta_n \approx 6\%$ in standard operation, which means $\eta_G \approx 40$ %. Typical CSD's are shown Fig. 2 and 3 for ^{39}K and ^{115}In.

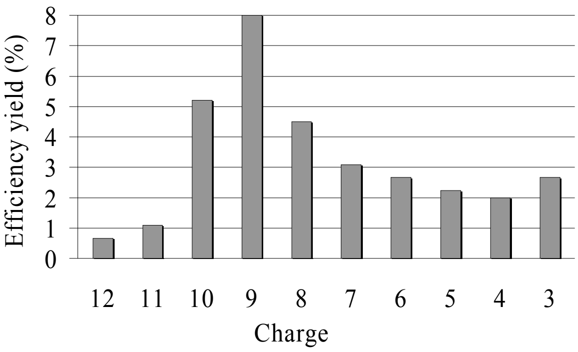

Figure 2: ^{39}K charge breeding efficiency.

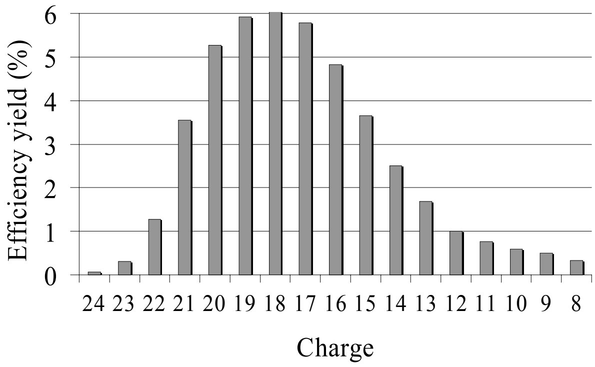

Figure 3: ^{115}In charge breeding efficiency.

3.3 Influence of the pressure on the charge state distribution

Many parameters can affect the CSD obtained by the 1+ → n+ process: the axial magnetic confinement, the RF power and the support gas pressure. Let us consider a $^{208}Pb^{2+}$ injection. After tuning the system to optimize ion capture, the support gas flux (O_2) is varied. Because of the position of the gauge, located in the injection chamber of PHOENIX, no significant pressure variation can be observed. However the effect of this variation on the CSD can clearly be seen (Fig. 4). Therefore one should consider this parameter as fundamental to get the highest efficiency on the expected charge.

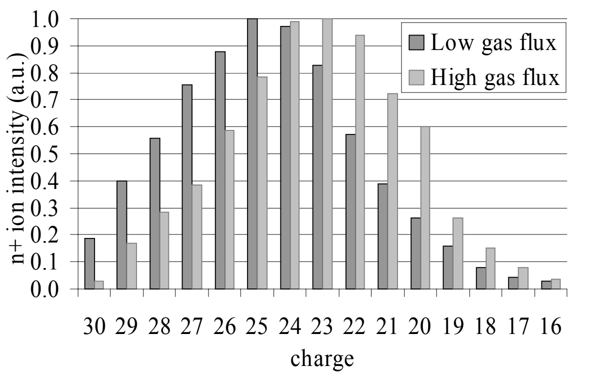

Figure 4: Charge state distribution versus gas flux.

3.4 Charge state dependence of charge breeding times

The charge breeding times τ_{cbt} strongly depend on the tuning parameters of the source (RF power, magnetic field, pressure). After optimising the ^{39}K charge breeding, we have experimentally measured τ_{cbt} for each pure ^{39}K charge state (without parasitic ion). The results are plotted Fig. 5. t = 0 being the injection time of the 1+ beam, we first clearly observe an increasing time shift for the extraction of the different charges, the 11+ appearing 12 ms after the 1+ injection. Moreover, the time to reach 90 % of the total extracted beam intensity depends linearly on the charge and is about 10 ms per charge (Fig. 6). An additional study should be performed to understand if this result is due to the better confinement of the higher charge states in the ECR plasma.

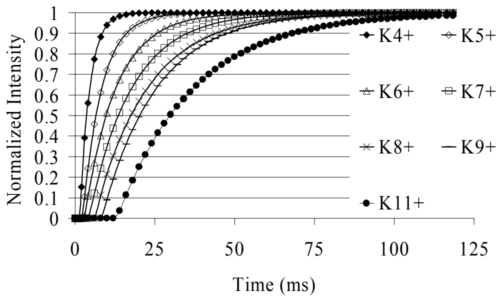

Figure 5: Potassium charge breeding times τ_{cbt}.

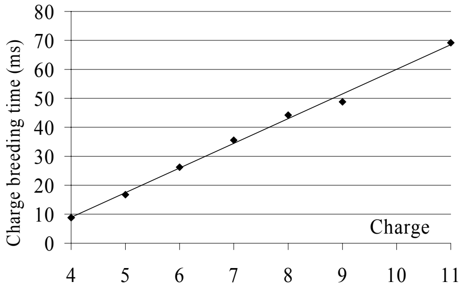

Figure 6: Linearity of the charge breeding time τ_{cbt}.

4 LEAD PRODUCTION

To get a more accurate understanding of the PHOENIX booster ECRIS, charge breeding studies have been performed with lead, either in cw mode or in pulsed one.

4.1 continuous working mode

In the context of RIB production, an efficiency of 7% with a CSD peaked in the range (21+ - 27+) has been obtained with a 500 nA $^{208}Pb^{2+}$ injected beam, which is consistent with the results explained in paragraph 3.2. When the injected current was increased up to 20 eμA the efficiency dropped to 2%, but the $^{208}Pb^{24+}$ extracted ion beam intensity reached 5 eμA. A typical CSD is shown in Fig. 7.

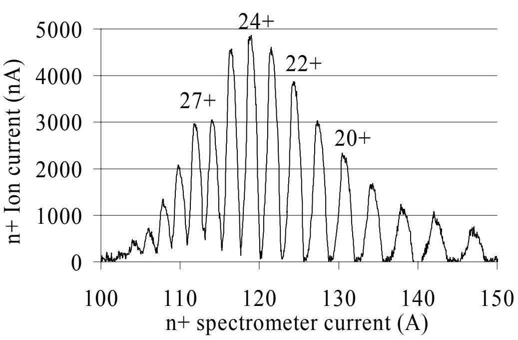

Figure 7: Pb^{n+} 1+ $\rightarrow$ n+ charge breeding.

This result clearly shows that the PHOENIX charge breeder remains efficient when injecting higher currents. The production of a "low charge-high intensity" ion beam, and its injection into a low pressure charge booster where the multi-ionization up to high charge states can take place, can be a very interesting production method for metallic ion beams [6].

4.2 Afterglow mode

The afterglow mode gives a good picture of the ions trapped in an ECRIS [7, 8] and therefore of its performance. When injecting 4 eμA of Pb^{2+}, we obtained the experimental Pb^{27+} signal (see Fig. 8) with a 100 μs plateau at 30 μA. In opposition to what we have observed with MINIMAFIOS, it is possible to tune the time structure of the signal.

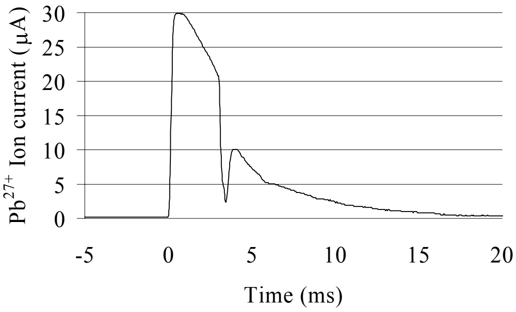

Figure 8: Pb^{27+} Afterglow signal.

5 CONCLUSION

A fast tuning of the PHOENIX charge booster gives a 3% efficiency yield on a specific charge for metallic ions (A $\geq$ 40 amu), the use of all the parameters available permits to increase this value to 6%. When tuned the beam extracted is stable at least for hours.

The lead production brings up a new method for metallic ion production, and demonstrates that the working of PHOENIX as a booster is comparable to classical 14 GHz ECRIS.

ACKNOWLEDGMENTS

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6 REFERENCES

[1] N. Chauvin, thèse de Doctorat Université Joseph Fourier Grenoble, Juillet 2000.
[2] P. Sortais et al., RNB2000 Conference proceedings, Nucl. Phys. A Vol. 701 pp. 537-549 (2002)
[3] T. Lamy et al., Rev. Sci. Instrum. Vol.**73,** nb.2, pp 717-719 (2002)
[4] T. Lamy et al., Proc. 14th International Workshop on ECR Sources, ECRIS99 pp 107-110
[5] R. Geller, Electron Cyclotron Resonance Ion Sources and ECR Plasmas (IoP, Bristol, 1996)
[6] C. Barue et al., Proc. International Workshop on ECR Sources, ECRIS99 pp 111-115
[7] P. Sortais, Rev. Sci. Instrum. **63**, 2801 (1992)
[8] N. Chauvin et al., Nucl. Instrum. Methods Phys. Res. A **419**, 185 (1998)